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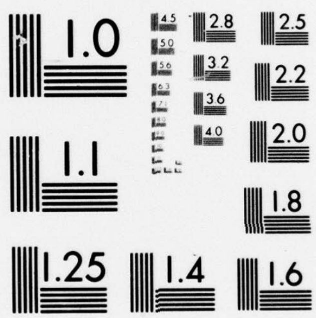

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(6) SASPRO--SPARE AND SERVER PROVISIONING PROGRAM.

by

(10) Donald Gross

(9) Scientific rept.,

(12) 25p.

(14) Serial-T-371
26 April 1978

(11) 26 Apr 78

The George Washington University
School of Engineering and Applied Science
Institute for Management Science and Engineering

Program in Logistics
(15) ~~Contract~~ N00014-75-C-0729
Project NR 347 020
Office of Naval Research

405 337

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NONE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER T-371	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) SASPRO-SPARE AND SERVER PROVISIONING PROGRAM		5. TYPE OF REPORT & PERIOD COVERED SCIENTIFIC
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) DONALD GROSS		8. CONTRACT OR GRANT NUMBER(s) N00014-75-C-0729
9. PERFORMING ORGANIZATION NAME AND ADDRESS THE GEORGE WASHINGTON UNIVERSITY PROGRAM IN LOGISTICS WASHINGTON, D. C. 20037		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS OFFICE OF NAVAL RESEARCH CODE 430D ARLINGTON, VIRGINIA 22217		12. REPORT DATE 26 April 1978
		13. NUMBER OF PAGES 23
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) NONE
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

DISTRIBUTION OF THIS REPORT IS UNLIMITED.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

SPARES PROVISIONING
INVENTORY
FINITE SOURCE QUEUES
MACHINE REPAIR PROBLEM

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

SASPRO is a versatile FORTRAN package designed to determine the level of spares inventory and number of repair channels necessary to provide a guaranteed service level at minimum cost for a population of stochastically failing, but completely repairable, items. The problem environment is first discussed, the program options are explained, and sample runs are provided.

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S/N 0102-014-6601

NONE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

THE GEORGE WASHINGTON UNIVERSITY
School of Engineering and Applied Science
Institute for Management Science and Engineering

Program in Logistics

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SASPRO--SPARE AND SERVER PROVISIONING PROGRAM

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1. Introduction

SASPRO, an acronym standing for *S*pare *a*nd *S*erver *Pro*visioning, is a versatile FORTRAN package that gives provisioning levels of spares inventory and repair capacity required to support a population of randomly failing items which, upon failure, are (1) dispatched to the repair facility, and (2) replaced by a spare if one is available. This paper describes in detail the problem environment, the program options, the input required to run the program, and the output provided by the program. Sample runs are also shown for each of the program options.

2. Problem Environment

A population of items containing certain key parts (for example, a fleet of aircraft, a fleet of ships, a group of machines) randomly fails and requires repair. Spare parts are also needed so that upon failure, the spare can be utilized to replace the failed part and the item put back into service. It is desired to determine how many spares and how many repair channels are required to support the system at a desired service level while minimizing costs.

The system is shown schematically in Figure 1. We consider only a single part-type at a time, which has its own spares pool and dedicated repair channels. For example, for a fleet of gas turbine propelled ships, the gas turbine engine has two components--a gas generator and a power turbine. Each must have dedicated repair channels and its own spares pool. Thus SASPRO would treat each component in turn, being utilized to provision first for a population of gas generators and then for a population of power turbines.

When a unit in the operating population fails, a spare is requested at the same time the unit is dispatched for repair. If a spare is not available, the request is backlogged and units coming out of repair are used in removing the backlog. When there is no backlog of requests for spares, units coming out of repair go into the spares inventory. Repair times as well as failure times are treated as random variables and with the proper assumptions (to be mentioned below), this stochastic process can be readily modeled as a finite source queueing system, often referred to as "the machine repair problem with spares," which, in addition, also fits a two-stage cyclic queueing model. Thus SASPRO uses a standard queueing model for the stochastic process [see GROSS, KAHN, and MARSH (1977)].

The assumptions required for using SASPRO are that times to failure and repair times are exponentially distributed random variables. These assumptions allow the employment of the standard finite source queueing theory to determine probabilities of various numbers of units in repair at any given time. From this, system service levels (number of units operating, availability of spares, etc.) can readily be computed.

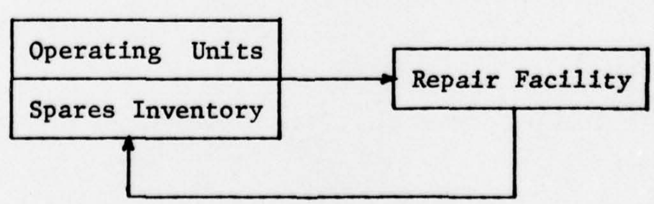

Figure 1. Problem environment.

In order to achieve a specified service level, certain combinations of spares and servers (repair channels) are required. Using costs associated with purchasing and holding spares, and costs associated with building and operating repair channels, SASPRO, through a heuristic optimization routine, finds the "best" combination of spares and servers that meets the service level constraint. [See Gross, *et al.* (1977) for specific details.]

3. Modes of Operation

The program has two modes of operation, dynamic and static. The former is advised for initial year provisioning when population sizes, failure rates, and repair times may be changing significantly. Population size changes may occur because units are put into operation gradually, thus building up to a full strength population over a period of several years. For example, it was anticipated to build a fleet of 256 gas turbine powered ships, starting in the first year with ten ships and building up to full strength over a ten-year period. Because of new technology, engines on ships introduced in the later years were expected to have smaller failure rates (be more reliable) while due to learning, repair times were also expected to be smaller in the later years.

In designing support systems for which it is necessary to determine the number and location of depots the static mode is useful [see GROSS and PINKUS (1978)]. In this situation the population is at full strength, technological advances and learning are complete, and conditions are very close to static. Running times and input requirements are greatly reduced when operating in the static mode.

The dynamic mode allows for changing population sizes, failure rates, and repair times, as well as for changing costs on a year by year basis. A set of input information is required for each year in the planning horizon. An item repaired and placed back into spares inventory (or operation) in year i is assumed to have the same failure rate as a new item introduced in year i .

All costs are turned into an equivalent beginning of year payment and then discounted according to where the year is in the planning horizon

so that at any year i the program gives the present worth of the cumulative sum of the discounted costs up to and including year i . The final value for the last year is then the present worth of the sum of discounted costs over the entire planning horizon.

The costs that are considered in SASPRO are purchase costs, salvage values, and annual operating costs associated with spares and repair channels; unit transportation and repair costs; and component improvement investment costs. Purchase costs and salvage values are in dollars per spare or repair channel, and salvage values are not realizable until the end of the planning horizon, even though spares or repair channels are retired prior to that. Operating costs of each channel and holding costs for spares are in dollars per year per spare or repair channel and any spare or channel purchased in year i is assumed to incur annual costs until the end of the planning horizon, even if retired earlier. Transportation and repair costs are in dollars per unit per repaired item and component improvement program (CIP) costs are in dollars per year.

The assumptions that salvage values are not received until the end of the planning horizon and that operating or holding costs are not reduced when spares or repair channels are retired early are necessitated by the heuristic optimization algorithm employed. Further, if a spare or repair channel is retired during the planning horizon and is required again a few years later, it must be repurchased. Again, this assumption is required because of the heuristic optimization algorithm.

In the static mode no such problems arise since spares and channels are not added or retired. Costs for this mode of operation are converted to expected equivalent end-of-year payments over the planning horizon.

4. Service Level Constraint Options

There are two options available for specifying service performance. The first, referred to as *spares availability*, sets a limit on the percentage of requests for spares that are met from on-shelf spares inventory (also called fill rate); that is,

$$\frac{\text{Number of Requests for Spares per Year Honored Immediately}}{\text{Number of Requests for Spares per Year}} \geqq A \;, \qquad (1)$$

where A is specified by the user and $0 < A < 1$.

The second criterion for service performance, called *"fleet" availability*, sets a level for the percentage of time a certain portion of the population desired to be in operation is actually operating; that is,

$$\Pr\{\geqq \beta M \text{ units are up}\} \geqq A \;. \qquad (2)$$

Both β and A are specified by the user when $0 < \beta \leqq 1$, and M is the population (fleet) size excluding spares.

Suppose, for example, we wish to have 100 machines in operation (M=100). When a machine fails, a spare machine is "plugged in" if one is available. We might specify that a service level constraint be (1) the percentage of requests for spare machines filled immediately from on-hand spares is at least 90% (option 1: A =.9), or (2) at least 95% of the machines are operating 85% of the time (option 2: β=.95, A=.85).

5. Input Data

Table I shows the data that are required as input for SASPRO.

Most input parameters are self-explanatory but a few require further comment. The A shown in Equations (1) and (2) is AVL, while BETA is the β shown in Equation (2).

The initial values C0 and Y0 must be read in for number of servers and spares, respectively. In the dynamic mode, after the first year the program uses the previous year's values for C0 and Y0 as initial values, even though a C0 and Y0 must be specified on the card set for every year in the planning horizon. The closer the initial values are to the final values (determined by SASPRO), the fewer iterations of the heuristic optimization algorithm are required. However, one may use C0 = Y0 = 1 if so desired.

TABLE I

INPUT REQUIREMENTS

Variable Name	Description	Symbol on Printout
AVL	Desired Availability	AVL
BETA	Desired Percent of Population Up	BETA
C	Initial Value--Number of Repair Channels	CO
CIC	Carrying Cost per Spare (\$/yr/spare)	CIC
CIPC	Component Improvement Cost (\$/yr)	CIPC
CPSER	Repair Channel (Server) Purchase Cost (\$/channel)	CPSER
CPSP	Spare Purchase Cost (\$/spare)	CPSP
H	Operating Hours per Year per Item (hrs)	H
KEYWD	Mode Option Indicator $\begin{cases} =1\text{: Dynamic} \\ \neq 1\text{: Static} \end{cases}$	KEYWD
KZ	Service Criterion Option Indicator $\begin{cases} \neq 1\text{: Spare Avl} \\ =1\text{: Fleet Avl} \end{cases}$	KZ
NYEARS	Planning Horizon Length (yrs)	YEARS
OCSPSER	Operating Cost of a Channel (\$/yr/channel)	OCPSER
R	Yearly Interest Rate	RATE
RM	Population Size	M
RMTBR	Mean Time Between Removals (hrs)	MTBR
ST	Average Turn Around Time (days)	1/MU
SVSER	Salvage Value of a Channel (\$/channel)	SVSER
SVSP	Salvage Value of a Spare (\$/spare)	SVSP
URC	Unit Repair Cost (\$/unit)	URC
UTC	Unit Transportation Cost (\$/unit)	UTC
Y	Initial Value--Number of Spares	YO

A set of cost inputs (CIC, CIPC, CPSER, CPSP, OCSPSER, SVSER, SVSP, URC, UTC) is required for each year in the horizon in the dynamic mode. This allows one to account for inflation and technological innovations. The Component Improvement Program Cost (CIPC) is the annual expenditure required to achieve a given MTBR schedule (the MTBR which must

be inputted for each year in the horizon) for the dynamic mode of operation, or to maintain the MTBR achieved when operating in the static mode.

The MTBR value is the actual mean time to failure of each unit when operating continuously. If items do not operate continuously but are required for, say, only H hours per year on the average, the mean failure rate actually used in the queueing model portion of SASPRO is lowered accordingly. If items do operate around the clock, $H = 365 \times 24 = 8760$. If, for example, a population of items has an MTBR of 1000 hours but is called upon to operate, on the average, only half the time ($H = 4380$ hours), the effective MTBR used in the program is raised to 2000 hours (failure rate cut in half). The user specifies H and MTBR and SASPRO automatically makes the adjustment. The reader is referred to BARZILY, GROSS, and KAHN (1977) for a discussion of the adequacy of this procedure to account for noncontinuous operation. The above reference also discusses the SASPRO assumptions, when operating in the dynamic mode, that (1) the population attains instantaneous steady-state each year at average values, and (2) the population consists of nonidentical units (with respect to mean failure and repair time), which are treated as identical by weighted averaging.

The parameters KEYWD and KZ are the option flags. Setting KEYWD=1 puts SASPRO in the dynamic mode; otherwise it operates in the static mode. Designating KZ=1 sets the service level on fleet availability; otherwise the service level constraint is on spares availability. A β must be specified when KZ=1 .

Table II and Figure 2 give the card layout required for the input information. There are eight cards needed for the static mode and six plus two cards for each year in the planning horizon required for dynamic mode operation. The input requirements for static mode operation are similar to those required for a one-year planning horizon dynamic run. However, the output cost values given in the static mode are the expected end of year payments adjusted over an NYEAR life, while the costs of a single year dynamic mode run are the present worth of expenditures for that year.

TABLE II

CARD LAYOUT FOR INPUT

Card Number	Input Data Parameter(s)	Format	Columns
1	Title (any desired by user)	--	1-80
2	NYEARS	I2	1-2
3	R	F8.5	1-8
4[a]	AVL, BETA	F8.5, F8.5	1-8, 9-16
5[b]	KZ	I2	1-2
6[c]	KEYWD	I2	1-2
7, 8	See Figure 2: One set required for each year in dynamic planning horizon; one set only for static mode.		

[a]For Spares Avail Option, BETA may be set at any value.

[b]$KZ = \begin{cases} 0 \rightarrow \text{Spares Availability} \\ 1 \rightarrow \text{Fleet Availability} \end{cases}$

[c]$KEYWD = \begin{cases} 0 \rightarrow \text{Static Mode} \\ 1 \rightarrow \text{Dynamic Mode} \end{cases}$

6. Output from SASPRO

SASPRO gives the heuristic optimum combination of spares and repair channels needed to meet the service level constraint and also provides the costs associated with this solution. For the static operation mode there is a single line of output with the total costs shown being the expected equivalent annual expenditure over the NYEAR system life. For the dynamic mode of operation there is a line of output for each year, the cost outputted being the expected present worth of the cumulative sum of discounted costs up to and including that year. Also given as output are the heuristic optimum combinations of servers and spares; the average system failure rate, which in the static mode is the same as the

M	Y0	C0	MTBR	1/MU	H	CIPC	CPSER	CPSP	URC	UTC
1 8	9 16	17 24	25 32	33 40	41 50	51 58	59 63	64 70	71 75	76 80
F8.0	F8.0	F8.0	F8.0	F8.0	F10.0	F8.0	F5.0	F7.0	F5.0	F5.0

SVPSER	SVPSP	OCPSER	CIC
1 5	6 12	13 17	18 26
F5.0	F7.0	F5.0	F5.0

Figure 2. Format for card set 6,7.

inputted failure rate calculated from the MTBR and H values read in, and in the dynamic mode is a weighted average of the units in the population which were introduced and repaired in various years at different values;[1] the average number of units repaired; and the actual availability achieved (always $\geq$ AVL). Another output quantity shown is ASTAR, the percentage of time the population is called upon to operate (ASTAR = H/8760); this serves as a check on the H value put in. The output quantities with definitions are shown in Table III.

TABLE III

OUTPUT QUANTITIES

Name	Description
YR	Actual year represented
M	Population size year i (from input)
FR	Failure rate of a unit purchased or repaired in year i (failures/day = $\frac{1}{MTBR} \cdot \frac{H}{8760} \cdot 24$)
FRBAR	Average failure rate of a typical unit (failures/day = weighted average of various units purchased or repaired in all years up to and including i)
ASTAR	Average percent of time population is called upon to operate (H/8760)
C	Heuristic optimum number of repair channels required in year i
Y	Heuristic optimum number of spares required in year i
RBAR	Average number of units repaired in year i
COST	Costs expended in year i dynamic mode or equivalent yearly average expenditure in static mode
PRES WORTH	Present worth of sum of discounted costs up to and including year i, dynamic mode; same as COST for static mode

[1]See Gross, Kahn, and Marsh (1977).

7. Sample Runs

We illustrate the model by showing sample runs for each mode (dynamic and static) for each service level option (spares availability and fleet availability). The first run is a dynamic, fleet availability, 20-year planning horizon case. Following this, a similar dynamic run is performed for spares availability. Next a static, 20-year system life spares availability situation is considered. Finally, a static, 20-year system life fleet availability case is run.

A listing of the input cards for these runs is given in Figure 3. For the four cases, there are a total of 108 data input cards $(2[6 + 2 \times 20] + 2[8])$.

The associated output for the cases is given in Figure 4.

8. Intermediate Output and the Heuristic Optimization Algorithm

Also provided as output are intermediate values of Y and C which "step up" from Y0 and C0 showing the operation of the algorithm at each iteration. Briefly, the algorithm works as follows.

First, a C_1 and C_2 are computed, where C_1 is a function of the purchase cost, operating cost, and salvage value of a repair channel and C_2 is a function of the purchase cost, carrying cost, and salvage value of a spare. In the dynamic mode, the functions for C_1 and C_2 , year i, are

$$C_1 = \text{CPSER} + \text{OCSPER}\left[\frac{(1+R)^{K-i+1} - 1}{R(1+R)^{K-i+1}}\right] - \text{SVSER}\left[\frac{1}{(1+R)^{K-i+1}}\right],$$

$$C_2 = \text{CPSP} + \text{CIC}\left[\frac{(1+R)^{K-i+1} - 1}{R(1+R)^{K-i+1}}\right] - \text{SVSP}\left[\frac{1}{(1+R)^{K-i+1}}\right], \tag{3}$$

where K is the total number of periods in the dynamic planning horizon, i the current year, R the interest rate, and the costs are as defined

```
SAMPLE RUN 1
20
0.10
0.95       0.95
1
1
   10.      1.     1.  3500.    65.   1880.30   0.  90.  616.5  49.   0.
32. 123.3  10.   82.2
   26.      6.     4.  3500.    62.5  1947.61   0.  90.  708.8  49.   0.
32. 141.8  10.   94.5
   50.     13.     5.  4250.    60.   2121.60   0.  90.  815.3  57.8  0.
32. 163.1  10.  106.7
   82.     13.     7.  5500.    57.5  1989.45   0.  90.  880.5  40.   0.
32. 170.1  10.  117.4
  121.     12.     7.  6500.    55.   1958.95   0.  90.  951.   42.   0.
32. 190.2  10.  126.8
  158.     11.     8.  7500.    55.   1966.37   0.  90. 1026.8  44.   0.
32. 205.35 10.  136.9
  182.     11.     8.  8500.    55.   1970.27   0.  90. 1026.8  44.   0.
32. 205.35 10.  136.9
  208.     11.     8.  9000.    55.   2001.90   0.  90. 1026.8  44.   0.
32. 205.35 10.  136.9
  229.     11.     8.  9000.    55.   2027.65   0.  90. 1026.8  44.   0.
32. 205.35 10.  136.9
  251.     11.     8.  9000.    55.   2040.44   0.  90. 1026.8  44.   0.
32. 205.35 10.  136.9
  256.     11.     8.  9000.    55.   2037.19   0.  90. 1026.8  44.   0.
32. 205.35 10.  136.9
  256.     11.     8.  9000.    55.   2037.19   0.  90. 1026.8  44.   0.
32. 205.35 10.  136.9
  256.     11.     8.  9000.    55.   2037.19   0.  90. 1026.8  44.   0.
32. 205.35 10.  136.9
  256.     11.     8.  9000.    55.   2037.19   0.  90. 1026.8  44.   0.
32. 205.35 10.  136.9
  256.     11.     8.  9000.    55.   2037.19   0.  90. 1026.8  44.   0.
32. 205.35 10.  136.9
  256.     11.     8.  9000.    55.   2037.19   0.  90. 1026.8  44.   0.
32. 205.35 10.  136.9
  256.     11.     8.  9000.    55.   2037.19   0.  90. 1026.8  44.   0.
32. 205.35 10.  136.9
  256.     11.     8.  9000.    55.   2037.19   0.  90. 1026.8  44.   0.
32. 205.35 10.  136.9
  256.     11.     8.  9000.    55.   2037.19   0.  90. 1026.8  44.   0.
32. 205.35 10.  136.9
  256.     11.     8.  9000.    55.   2037.19   0.  90. 1026.8  44.   0.
32. 205.35 10.  136.9
SAMPLE RUN 2
20
0.10
0.90       1.00
0
1
   10.      1.     1.  3500.    65.   1880.30   0.  90.  616.5  49.   0.
32. 123.3  10.   82.2
   26.      6.     4.  3500.    62.5  1947.61   0.  90.  708.8  49.   0.
32. 141.8  10.   94.5
   50.     13.     5.  4250.    60.   2121.60   0.  90.  815.3  57.8  0.
32. 163.1  10.  106.7
   82.     13.     7.  5500.    57.5  1989.45   0.  90.  880.5  40.   0.
32. 170.1  10.  117.4
  121.     12.     7.  6500.    55.   1958.95   0.  90.  951.   42.   0.
32. 190.2  10.  126.8
  158.     11.     8.  7500.    55.   1966.37   0.  90. 1026.8  44.   0.
32. 205.35 10.  136.9
  182.     11.     8.  8500.    55.   1970.27   0.  90. 1026.8  44.   0.
32. 205.35 10.  136.9
  208.     11.     8.  9000.    55.   2001.90   0.  90. 1026.8  44.   0.
32. 205.35 10.  136.9
  229.     11.     8.  9000.    55.   2027.65   0.  90. 1026.8  44.   0.
32. 205.35 10.  136.9
  251.     11.     8.  9000.    55.   2040.44   0.  90. 1026.8  44.   0.
32. 205.35 10.  136.9
  256.     11.     8.  9000.    55.   2037.19   0.  90. 1026.8  44.   0.
32. 205.35 10.  136.9
  256.     11.     8.  9000.    55.   2037.19   0.  90. 1026.8  44.   0.
32. 205.35 10.  136.9
  256.     11.     8.  9000.    55.   2037.19   0.  90. 1026.8  44.   0.
32. 205.35 10.  136.9
  256.     11.     8.  9000.    55.   2037.19   0.  90. 1026.8  44.   0.
32. 205.35 10.  136.9
  256.     11.     8.  9000.    55.   2037.19   0.  90. 1026.8  44.   0.
32. 205.35 10.  136.9
  256.     11.     8.  9000.    55.   2037.19   0.  90. 1026.8  44.   0.
32. 205.35 10.  136.9
  256.     11.     8.  9000.    55.   2037.19   0.  90. 1026.8  44.   0.
32. 205.35 10.  136.9
  256.     11.     8.  9000.    55.   2037.19   0.  90. 1026.8  44.   0.
32. 205.35 10.  136.9
  256.     11.     8.  9000.    55.   2037.19   0.  90. 1026.8  44.   0.
32. 205.35 10.  136.9
  256.     11.     8.  9000.    55.   2037.19   0.  90. 1026.8  44.   0.
32. 205.35 10.  136.9
SAMPLE RUN 3
20
0.10
0.90       1.00
0
0
  256.     11.     8.  9000.    55.   2037.19   0.  90. 1026.8  44.   0.
32. 205.35 10.  136.9
SAMPLE RUN 4
20
0.10
0.90       0.95
1
0
  256.      1.    12.  9000.    55.   2037.19   0.  90. 1026.8  44.   0.
32. 205.35 10.  136.9
```

Figure 3. Input card listing for sample runs.

```
                              SAMPLE RUN 1

                    DYNAMIC MODEL: FLEET AVAIL OPTION

INPUT DATA
YRS RATE     M  AVL  BETA  YO   CO   MTBR    1/MU      H CPSER  CPSP  URC   CIPC UTC SVPSER SVPSP OCPSER CIC
 20 .100   10. .950  0.95  1.   1.   3500.  65.000  1880.  90.   617.  49.   0.  0.0  32.   123.   10.   82.

OUTPUT DATA
YR  M       FR          FRBAR      ASTAR     C      Y   RBAR       COST    PR-WORTH
75  10  0.00147186  0.00147186  0.214646     3      3    5.3     4642.01    4642.01

INPUT DATA
YRS RATE     M  AVL  BETA  YO   CO   MTBR    1/MU      H CPSER  CPSP  URC   CIPC UTC SVPSER SVPSP OCPSER CIC
 20 .100   28. .950  0.95  6.   4.   3500.  62.500  1948.  90.   709.  49.   0.  0.0  32.   142.   10.   95.

OUTPUT DATA
YR  M       FR          FRBAR      ASTAR     C      Y   RBAR       COST    PR-WORTH
76  28  0.00152455  0.00150573  0.222330     7      4   15.3     2829.96    7214.71

INPUT DATA
YRS RATE     M  AVL  BETA  YO   CO   MTBR    1/MU      H CPSER  CPSP  URC   CIPC UTC SVPSER SVPSP OCPSER CIC
 20 .100   50. .950  0.95 13.   5.   4250.  60.000  2122.  90.   815.  38.   0.  0.0  32.   163.   10.  109.

OUTPUT DATA
YR  M       FR          FRBAR      ASTAR     C      Y   RBAR       COST    PR-WORTH
77  50  0.00136767  0.00145073  0.242192     8      6   26.3     4423.27   10870.31

INPUT DATA
YRS RATE     M  AVL  BETA  YO   CO   MTBR    1/MU      H CPSER  CPSP  URC   CIPC UTC SVPSER SVPSP OCPSER CIC
 20 .100   82. .950  0.95 13.   7.   5500.  57.500  1989.  90.   881.  40.   0.  0.0  32.   176.   10.  117.

OUTPUT DATA
YR  M       FR          FRBAR      ASTAR     C      Y   RBAR       COST    PR-WORTH
78  82  0.00099101  0.00124474  0.227106    10      6   36.8     1665.32   12121.49

INPUT DATA
YRS RATE     M  AVL  BETA  YO   CO   MTBR    1/MU      H CPSER  CPSP  URC   CIPC UTC SVPSER SVPSP OCPSER CIC
 20 .100  121. .950  0.95 12.   7.   6500.  55.000  1959.  90.   951.  42.   0.  0.0  32.   190.   10.  127.

OUTPUT DATA
YR  M       FR          FRBAR      ASTAR     C      Y   RBAR       COST    PR-WORTH
79 121  0.00082569  0.00103254  0.223624    10      6   44.8     1710.51   13289.79

INPUT DATA
YRS RATE     M  AVL  BETA  YO   CO   MTBR    1/MU      H CPSER  CPSP  URC   CIPC UTC SVPSER SVPSP OCPSER CIC
 20 .100  158. .950  0.95 11.   8.   7500.  55.000  1966.  90.  1027.  44.   0.  0.0  32.   205.   10.  137.

OUTPUT DATA
YR  M       FR          FRBAR      ASTAR     C      Y   RBAR       COST    PR-WORTH
80 158  0.00071831  0.00090031  0.224471    14      5   51.0     2671.92   14948.84

INPUT DATA
YRS RATE     M  AVL  BETA  YO   CO   MTBR    1/MU      H CPSER  CPSP  URC   CIPC UTC SVPSER SVPSP OCPSER CIC
 20 .100  182. .950  0.95 11.   8.   8500.  55.000  1976.  90.  1027.  44.   0.  0.0  32.   205.   10.  137.

OUTPUT DATA
YR  M       FR          FRBAR      ASTAR     C      Y   RBAR       COST    PR-WORTH
81 182  0.00063699  0.00081463  0.225602    13      4   52.9     2114.15   16142.22

INPUT DATA
YRS RATE     M  AVL  BETA  YO   CO   MTBR    1/MU      H CPSER  CPSP  URC   CIPC UTC SVPSER SVPSP OCPSER CIC
 20 .100  208. .950  0.95 11.   8.   9000.  55.000  2002.  90.  1027.  44.   0.  0.0  32.   205.   10.  137.

OUTPUT DATA
YR  M       FR          FRBAR      ASTAR     C      Y   RBAR       COST    PR-WORTH
82 208  0.00060961  0.00074380  0.228527    13      4   55.2     2207.91   17275.23

INPUT DATA
YRS RATE     M  AVL  BETA  YO   CO   MTBR    1/MU      H CPSER  CPSP  URC   CIPC UTC SVPSER SVPSP OCPSER CIC
 20 .100  229. .950  0.95 11.   8.   9000.  55.000  2028.  90.  1027.  44.   0.  0.0  32.   205.   10.  137.

OUTPUT DATA
YR  M       FR          FRBAR      ASTAR     C      Y   RBAR       COST    PR-WORTH
83 229  0.00061725  0.00069982  0.231467    13      3   57.0     2278.12   18337.99

INPUT DATA
YRS RATE     M  AVL  BETA  YO   CO   MTBR    1/MU      H CPSER  CPSP  URC   CIPC UTC SVPSER SVPSP OCPSER CIC
 20 .100  251. .950  0.95 11.   8.   9000.  55.000  2046.  90.  1027.  44.   0.  0.0  32.   205.   10.  137.

OUTPUT DATA
YR  M       FR          FRBAR      ASTAR     C      Y   RBAR       COST    PR-WORTH
84 251  0.00062296  0.00067435  0.233612    13      3   60.1     2404.39   19357.66
```

Figure 4. Sample run output.

```
INPUT DATA
YRS RATE     M   AVL  BETA   YO   CO    MTBR    1/MU      H  CPSER  CPSP   URC   CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 20  .100  256. .950  0.95  11.   8.   9000.  55.000  2037.   90.  1027.   44.    0.   0.0   32.    205.   10.  137.

OUTPUT DATA
YR   M       FR          FRBAR       ASTAR      C      Y    RBAR      COST     PR=WORTH
85  256  0.00062015   0.00066123   0.232556   13      3    60.1   2405.76   20265.21

INPUT DATA
YRS RATE     M   AVL  BETA   YO   CO    MTBR    1/MU      H  CPSER  CPSP   URC   CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 20  .100  256. .950  0.95  11.   8.   9000.  55.000  2037.   90.  1027.   44.    0.   0.0   32.    205.   10.  137.

OUTPUT DATA
YR   M       FR          FRBAR       ASTAR      C      Y    RBAR      COST     PR=WORTH
86  256  0.00062015   0.00065158   0.232556   13      3    59.3   2372.63   21116.80

INPUT DATA
YRS RATE     M   AVL  BETA   YO   CO    MTBR    1/MU      H  CPSER  CPSP   URC   CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 20  .100  256. .950  0.95  11.   8.   9000.  55.000  2037.   90.  1027.   44.    0.   0.0   32.    205.   10.  137.

OUTPUT DATA
YR   M       FR          FRBAR       ASTAR      C      Y    RBAR      COST     PR=WORTH
87  256  0.00062015   0.00064429   0.232556   13      3    58.7   2347.55   21864.80

INPUT DATA
YRS RATE     M   AVL  BETA   YO   CO    MTBR    1/MU      H  CPSER  CPSP   URC   CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 20  .100  256. .950  0.95  11.   8.   9000.  55.000  2037.   90.  1027.   44.    0.   0.0   32.    205.   10.  137.

OUTPUT DATA
YR   M       FR          FRBAR       ASTAR      C      Y    RBAR      COST     PR=WORTH
88  256  0.00062015   0.00063676   0.232556   13      3    58.2   2328.43   22539.20

INPUT DATA
YRS RATE     M   AVL  BETA   YO   CO    MTBR    1/MU      H  CPSER  CPSP   URC   CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 20  .100  256. .950  0.95  11.   8.   9000.  55.000  2037.   90.  1027.   44.    0.   0.0   32.    205.   10.  137.

OUTPUT DATA
YR   M       FR          FRBAR       ASTAR      C      Y    RBAR      COST     PR=WORTH
89  256  0.00062015   0.00063453   0.232556   13      3    57.8   2313.78   23148.55

INPUT DATA
YRS RATE     M   AVL  BETA   YO   CO    MTBR    1/MU      H  CPSER  CPSP   URC   CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 20  .100  256. .950  0.95  11.   8.   9000.  55.000  2037.   90.  1027.   44.    0.   0.0   32.    205.   10.  137.

OUTPUT DATA
YR   M       FR          FRBAR       ASTAR      C      Y    RBAR      COST     PR=WORTH
90  256  0.00062015   0.00063128   0.232556   13      2    57.3   2293.83   23697.68

INPUT DATA
YRS RATE     M   AVL  BETA   YO   CO    MTBR    1/MU      H  CPSER  CPSP   URC   CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 20  .100  256. .950  0.95  11.   8.   9000.  55.000  2037.   90.  1027.   44.    0.   0.0   32.    205.   10.  137.

OUTPUT DATA
YR   M       FR          FRBAR       ASTAR      C      Y    RBAR      COST     PR=WORTH
91  256  0.00062015   0.00062879   0.232556   13      2    57.1   2285.21   24195.01

INPUT DATA
YRS RATE     M   AVL  BETA   YO   CO    MTBR    1/MU      H  CPSER  CPSP   URC   CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 20  .100  256. .950  0.95  11.   8.   9000.  55.000  2037.   90.  1027.   44.    0.   0.0   32.    205.   10.  137.

OUTPUT DATA
YR   M       FR          FRBAR       ASTAR      C      Y    RBAR      COST     PR=WORTH
92  256  0.00062015   0.00062686   0.232556   13      2    57.0   2278.54   24645.80

INPUT DATA
YRS RATE     M   AVL  BETA   YO   CO    MTBR    1/MU      H  CPSER  CPSP   URC   CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 20  .100  256. .950  0.95  11.   8.   9000.  55.000  2037.   90.  1027.   44.    0.   0.0   32.    205.   10.  137.

OUTPUT DATA
YR   M       FR          FRBAR       ASTAR      C      Y    RBAR      COST     PR=WORTH
93  256  0.00062015   0.00062537   0.232556   13      2    56.8   2273.37   25054.69

INPUT DATA
YRS RATE     M   AVL  BETA   YO   CO    MTBR    1/MU      H  CPSER  CPSP   URC   CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 20  .100  256. .950  0.95  11.   8.   9000.  55.000  2037.   90.  1027.   44.    0.   0.0   32.    205.   10.  137.

OUTPUT DATA
YR   M       FR          FRBAR       ASTAR      C      Y    RBAR      COST     PR=WORTH
94  256  0.00062015   0.00062421   0.232556   13      2    56.7   2269.36   25425.75
```

Figure 4.--*continued*

```
                              SAMPLE RUN 2

                     DYNAMIC MODEL: SPARES AVAIL OPTION
INPUT DATA
YRS RATE      M  AVL  BETA   YO   CO    MTBR    1/MU        H CPSER  CPSP   URC    CIPC  UTC SVPSER  SVPSP OCPSER  CIC
 20 .100    10. .900  1.00   1.   1.   3500.  65.000    1880.   90.  617.   49.      0.  0.0   32.    123.   10.   82.
OUTPUT DATA
YR   M         FR        FRBAR     ASTAR       C       Y    RBAR       COST      PR-WORTH
75  10  0.00147186  0.00147186  0.214646       3       3     5.3    4642.01       4642.01
INPUT DATA
YRS RATE      M  AVL  BETA   YO   CO    MTBR    1/MU        H CPSER  CPSP   URC    CIPC  UTC SVPSER  SVPSP OCPSER  CIC
 20 .100    28. .900  1.00   6.   4.   3500.  62.500    1948.   90.  709.   49.      0.  0.0   32.    142.   10.   95.
OUTPUT DATA
YR   M         FR        FRBAR     ASTAR       C       Y    RBAR       COST      PR-WORTH
76  28  0.00152455  0.00150573  0.222330       5       6    15.3    5445.33       9592.31
INPUT DATA
YRS RATE      M  AVL  BETA   YO   CO    MTBR    1/MU        H CPSER  CPSP   URC    CIPC  UTC SVPSER  SVPSP OCPSER  CIC
 20 .100    50. .900  1.00  13.   5.   4250.  60.000    2122.   90.  815.   38.      0.  0.0   32.    163.   10.  109.
OUTPUT DATA
YR   M         FR        FRBAR     ASTAR       C       Y    RBAR       COST      PR-WORTH
77  50  0.00136767  0.00145073  0.242192       8       8    20.4    4760.54      13526.65
INPUT DATA
YRS RATE      M  AVL  BETA   YO   CO    MTBR    1/MU        H CPSER  CPSP   URC    CIPC  UTC SVPSER  SVPSP OCPSER  CIC
 20 .100    82. .900  1.00  13.   7.   5500.  57.500    1989.   90.  881.   40.      0.  0.0   32.    176.   10.  117.
OUTPUT DATA
YR   M         FR        FRBAR     ASTAR       C       Y    RBAR       COST      PR-WORTH
78  82  0.00099101  0.00124460  0.227106      10      10    37.2    5254.03      17474.08
INPUT DATA
YRS RATE      M  AVL  BETA   YO   CO    MTBR    1/MU        H CPSER  CPSP   URC    CIPC  UTC SVPSER  SVPSP OCPSER  CIC
 20 .100   121. .900  1.00  12.   7.   6500.  55.000    1959.   90.  951.   42.      0.  0.0   32.    190.   10.  127.
OUTPUT DATA
YR   M         FR        FRBAR     ASTAR       C       Y    RBAR       COST      PR-WORTH
79 121  0.00082569  0.00103169  0.223624      12      11    45.5    3961.55      20179.87
INPUT DATA
YRS RATE      M  AVL  BETA   YO   CO    MTBR    1/MU        H CPSER  CPSP   URC    CIPC  UTC SVPSER  SVPSP OCPSER  CIC
 20 .100   158. .900  1.00  11.   8.   7500.  55.000    1966.   90. 1027.   44.      0.  0.0   32.    205.   10.  137.
OUTPUT DATA
YR   M         FR        FRBAR     ASTAR       C       Y    RBAR       COST      PR-WORTH
80 158  0.00071831  0.00089898  0.224471      15      12    51.8    4566.19      23015.11
INPUT DATA
YRS RATE      M  AVL  BETA   YO   CO    MTBR    1/MU        H CPSER  CPSP   URC    CIPC  UTC SVPSER  SVPSP OCPSER  CIC
 20 .100   182. .900  1.00  11.   8.   8500.  55.000    1976.   90. 1027.   44.      0.  0.0   32.    205.   10.  137.
OUTPUT DATA
YR   M         FR        FRBAR     ASTAR       C       Y    RBAR       COST      PR-WORTH
81 182  0.00063699  0.00081301  0.225602      13      13    53.9    4139.14      25351.55
INPUT DATA
YRS RATE      M  AVL  BETA   YO   CO    MTBR    1/MU        H CPSER  CPSP   URC    CIPC  UTC SVPSER  SVPSP OCPSER  CIC
 20 .100   208. .900  1.00  11.   8.   9000.  55.000    2002.   90. 1027.   44.      0.  0.0   32.    205.   10.  137.
OUTPUT DATA
YR   M         FR        FRBAR     ASTAR       C       Y    RBAR       COST      PR-WORTH
82 208  0.00060941  0.00074196  0.226527      14      13    56.3    2402.66      26564.50
INPUT DATA
YRS RATE      M  AVL  BETA   YO   CO    MTBR    1/MU        H CPSER  CPSP   URC    CIPC  UTC SVPSER  SVPSP OCPSER  CIC
 20 .100   229. .900  1.00  11.   8.   9000.  55.000    2028.   90. 1027.   44.      0.  0.0   32.    205.   10.  137.
OUTPUT DATA
YR   M         FR        FRBAR     ASTAR       C       Y    RBAR       COST      PR-WORTH
83 229  0.00061725  0.00069791  0.231467      13      14    58.3    4224.40      28555.21
INPUT DATA
YRS RATE      M  AVL  BETA   YO   CO    MTBR    1/MU        H CPSER  CPSP   URC    CIPC  UTC SVPSER  SVPSP OCPSER  CIC
 20 .100   251. .900  1.00  11.   8.   9000.  55.000    2046.   90. 1027.   44.      0.  0.0   32.    205.   10.  137.
OUTPUT DATA
YR   M         FR        FRBAR     ASTAR       C       Y    RBAR       COST      PR-WORTH
84 251  0.00062296  0.00067262  0.233612      15      14    61.6    2750.36      24721.63
```

Figure 4.--*continued*

```
INPUT DATA
YRS  RATE     M   AVL  BETA   YO   CO    MTBR    1/MU      M  CPSER  CPSP   UHC   CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 20  .100  256.  .900  1.00  11.   8.   9000.  55.000  2037.    90. 1027.   44.    0.   0.0    32.    205.   10.  137.
OUTPUT DATA
YR    M          FR         FRBAR    ASTAR      C      Y   RBAR     COST    PR-WORTH
85  256  0.00062015  0.00065905  0.232556     15     14   61.6  2463.55    30671.44
INPUT DATA
YRS  RATE     M   AVL  BETA   YO   CO    MTBR    1/MU      M  CPSER  CPSP   UHC   CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 20  .100  256.  .900  1.00  11.   8.   9000.  55.000  2037.    90. 1027.   44.    0.   0.0    32.    205.   10.  137.
OUTPUT DATA
YR    M          FR         FRBAR    ASTAR      C      Y   RBAR     COST    PR-WORTH
86  256  0.00062015  0.00065015  0.232556     14     14   60.7  2427.43    31522.24
INPUT DATA
YRS  RATE     M   AVL  BETA   YO   CO    MTBR    1/MU      M  CPSER  CPSP   UHC   CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 20  .100  256.  .900  1.00  11.   8.   9000.  55.000  2037.    90. 1027.   44.    0.   0.0    32.    205.   10.  137.
OUTPUT DATA
YR    M          FR         FRBAR    ASTAR      C      Y   RBAR     COST    PR-WORTH
87  256  0.00062015  0.00064304  0.232556     14     14   60.0  2401.14    32287.32
INPUT DATA
YRS  RATE     M   AVL  BETA   YO   CO    MTBR    1/MU      M  CPSER  CPSP   UHC   CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 20  .100  256.  .900  1.00  11.   8.   9000.  55.000  2037.    90. 1027.   44.    0.   0.0    32.    205.   10.  137.
OUTPUT DATA
YR    M          FR         FRBAR    ASTAR      C      Y   RBAR     COST    PR-WORTH
88  256  0.00062015  0.00063767  0.232556     14     14   59.5  2381.28    32977.09
INPUT DATA
YRS  RATE     M   AVL  BETA   YO   CO    MTBR    1/MU      M  CPSER  CPSP   UHC   CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 20  .100  256.  .900  1.00  11.   8.   9000.  55.000  2037.    90. 1027.   44.    0.   0.0    32.    205.   10.  137.
OUTPUT DATA
YR    M          FR         FRBAR    ASTAR      C      Y   RBAR     COST    PR-WORTH
89  256  0.00062015  0.00063360  0.232556     14     14   59.2  2366.19    33600.18
INPUT DATA
YRS  RATE     M   AVL  BETA   YO   CO    MTBR    1/MU      M  CPSER  CPSP   UHC   CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 20  .100  256.  .900  1.00  11.   8.   9000.  55.000  2037.    90. 1027.   44.    0.   0.0    32.    205.   10.  137.
OUTPUT DATA
YR    M          FR         FRBAR    ASTAR      C      Y   RBAR     COST    PR-WORTH
90  256  0.00062015  0.00063049  0.232556     13     14   58.8  2353.31    34163.54
INPUT DATA
YRS  RATE     M   AVL  BETA   YO   CO    MTBR    1/MU      M  CPSER  CPSP   UHC   CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 20  .100  256.  .900  1.00  11.   8.   9000.  55.000  2037.    90. 1027.   44.    0.   0.0    32.    205.   10.  137.
OUTPUT DATA
YR    M          FR         FRBAR    ASTAR      C      Y   RBAR     COST    PR-WORTH
91  256  0.00062015  0.00062811  0.232556     13     14   58.6  2344.56    34673.79
INPUT DATA
YRS  RATE     M   AVL  BETA   YO   CO    MTBR    1/MU      M  CPSER  CPSP   UHC   CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 20  .100  256.  .900  1.00  11.   8.   9000.  55.000  2037.    90. 1027.   44.    0.   0.0    32.    205.   10.  137.
OUTPUT DATA
YR    M          FR         FRBAR    ASTAR      C      Y   RBAR     COST    PR-WORTH
92  256  0.00062015  0.00062629  0.232556     13     14   58.4  2337.85    35136.32
INPUT DATA
YRS  RATE     M   AVL  BETA   YO   CO    MTBR    1/MU      M  CPSER  CPSP   UHC   CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 20  .100  256.  .900  1.00  11.   8.   9000.  55.000  2037.    90. 1027.   44.    0.   0.0    32.    205.   10.  137.
OUTPUT DATA
YR    M          FR         FRBAR    ASTAR      C      Y   RBAR     COST    PR-WORTH
93  256  0.00062015  0.00062489  0.232556     13     14   58.3  2332.68    35555.87
INPUT DATA
YRS  RATE     M   AVL  BETA   YO   CO    MTBR    1/MU      M  CPSER  CPSP   UHC   CIPC  UTC  SVPSER  SVPSP OCPSER  CIC
 20  .100  256.  .900  1.00  11.   8.   9000.  55.000  2037.    90. 1027.   44.    0.   0.0    32.    205.   10.  137.
OUTPUT DATA
YR    M          FR         FRBAR    ASTAR      C      Y   RBAR     COST    PR-WORTH
94  256  0.00062015  0.00062381  0.232556     13     14   58.2  2328.71    35936.63
```

Figure 4.--*continued*

```
                                SAMPLE RUN 3

                                STATIC MODEL: SPARES AVAIL OPTION
INPUT DATA
YRS  RATE     M   AVL   BETA   YO    CO     MTBR     1/MU        M  CPSER   CPSP    URC      CIPC  UTC  SVPSER   SVPSP OCPSER  CIC
 20  .100  256.  .900   1.00  11.    8.    9000.   55.000     2037.    90.  1027.    44.        0.   0.0    32.     205.    10.  137.
OUTPUT DATA
YR   M       FR          FRBAR      ASTAR        C         Y       RBAR       COST        PR-WORTH
75  256  0.00062015   0.00062015  0.232556      13        14       57.9      6361.81      6361.81


                                SAMPLE RUN 4

                                STATIC MODEL: FLEET AVAIL OPTION
INPUT DATA
YRS  RATE     M   AVL   BETA   YO    CO     MTBR     1/MU        M  CPSER   CPSP    URC      CIPC  UTC  SVPSER   SVPSP OCPSER  CIC
 20  .100  256.  .900   0.95  11.    8.    9000.   55.000     2037.    90.  1027.    44.        0.   0.0    32.     205.    10.  137.
OUTPUT DATA
YR   M       FR          FRBAR      ASTAR        C         Y       RBAR       COST        PR-WORTH
75  256  0.00062015   0.00062015  0.232556      12         1       56.1      2960.50      2960.50
```

Figure 4.--*continued*

in Table I. The first bracket term brings the annual costs, OCSPER and CIC, to a beginning of year i equivalent cost, while the second bracket term brings the salvage value to a beginning of year i equivalent term; that is, the bracket terms are the present worth factors for a series payment and end of horizon payment, respectively. Note it is assumed that if a spare or repair channel is purchased in year i, the annual costs are incurred through the end of the planning horizon and salvage cannot be obtained until the end of the horizon, even if removal occurs sooner.

The algorithm forms a ratio (call Δ) of C_1/C_2 or C_2/C_1 , depending on the relative magnitudes in such a way that the ratio is ≥ 1 . Then given a pair of values C,Y (to start year i, C_{i-1} and Y_{i-1} are used) the availability is computed. If it is below the desired level and if $\Delta = C_1/C_2$, then for an equal dollar expenditure Δ repair channels or one spare can be added. Availability is calculated for both cases (adding Δ repair channels or one spare) and the case yielding the higher availability becomes the new C,Y pair. The algorithm repeats until the desired availability is met. Upon exceeding the desired availability, a backoff procedure is utilized. If feasibility was reached by adding Δ channels, the algorithm first attempts to remove a spare and then channels are removed one at a time to see if a cheaper solution exists near the boundary. If feasibility was reached by adding a spare, again one-at-a-time removal of channels is tried. Had $\Delta = C_2/C_1$, the words channel and spare would be reversed in describing the algorithm.

When the initial values of C and Y for year i exceed the availability desired, the algorithm immediately goes into a backoff mode, trying to remove spares and channels one at a time, starting with the more expensive (larger C_i value) first.

The algorithm uses only C_1 and C_2 . The other costs are used in calculating the total year i expenditures even though they are not used in the algorithm. The costs URC, UTC, and CIPC are assumed year end expenditures and are multiplied by $1/(1+R)$ to bring them back to

a year beginning cost. The URC and UTC costs are multiplied by $\bar{R}$ and then added to $C_1\times$(number of new channels added) + $C_2\times$(number of new spares added) + CIPC to yield the total beginning of year cost for year i (call T_c) which is outputted. Letting $\alpha = 1/(1+R)$, the discounting factor, the final cost figure given in the output for year i is the present worth of the cumulative sum of equivalent beginning of year costs, up to and including year i; namely, $\sum_{j=1}^{i} \alpha^{j-1} T_j$.

In the static mode the algorithm works in the same way, except the functions C_1 and C_2 are changed to reflect all costs as average expenditures per year. Thus, the purchase costs and salvage values are multiplied by sinking fund and capital recovery factors, namely,

$$\begin{aligned} C_1 &= \text{CPSER}\left[\frac{R(1+R)^K}{(1+R)^K - 1}\right] + \text{OCSPER} - \text{SVSER}\left[\frac{R}{(1+R)^K - 1}\right] \\ C_2 &= \text{CPSP}\left[\frac{R(1+R)^K}{(1+R)^K - 1}\right] + \text{CIC} - \text{SVSP}\left[\frac{R}{(1+R)^K - 1}\right] . \end{aligned} \tag{4}$$

In this mode total equivalent expenditures per year are calculated simply by adding $(\text{URC} + \text{UTC})\bar{R}$ and CIPC to $C_1\times(C) + C_2\times(Y)$. This is then the value which shows as both COST and PRES WORTH on the output, the PRES WORTH column being meaningless in the static mode.

A sample of intermediate output is shown in Figure 5 for the first year of sample run 1. Shown are the failure rate for year i (RLAM), average population failure rate for year i (AMTBR), average turn around (repair) time (ST), availability for the particular combination of C and Y , average queue size at repair depot (LQ), and average number of units in repair (L).

9. Acknowledgments

The computer programming was originally performed by H. D. Kahn and modified by F. Ghotb and M. Y. Wong. Their excellent assistance was invaluable in yielding the SASPRO package.

```
M=  10.0 C=  1.0 Y=  1.0 RLAM=0.147186D-02 AMTBR=0.0014719 ST= 65.000 AVAIL=0.38615D 00 LQ= 0.1610D 01 L=  2.4129
M=  10.0 C=  8.0 Y=  1.0 RLAM=0.147186D-02 AMTBR=0.0014719 ST= 65.000 AVAIL=0.76002D 00 LQ= 0.1538D-07 L=  0.9266
M=  10.0 C=  1.0 Y=  2.0 RLAM=0.147186D-02 AMTBR=0.0014719 ST= 65.000 AVAIL=0.49112D 00 LQ= 0.2000D 01 L=  2.8293
M=  10.0 C= 15.0 Y=  1.0 RLAM=0.147186D-02 AMTBR=0.0014719 ST= 65.000 AVAIL=0.76002D 00 LQ= 0.0        L=  0.9266
M=  10.0 C=  8.0 Y=  2.0 RLAM=0.147186D-02 AMTBR=0.0014719 ST= 65.000 AVAIL=0.92963D 00 LQ= 0.5208D-07 L=  0.9484
M=  10.0 C= 15.0 Y=  2.0 RLAM=0.147186D-02 AMTBR=0.0014719 ST= 65.000 AVAIL=0.92963D 00 LQ= 0.0        L=  0.9484
M=  10.0 C=  8.0 Y=  3.0 RLAM=0.147186D-02 AMTBR=0.0014719 ST= 65.000 AVAIL=0.98395D 00 LQ= 0.1332D-06 L=  0.9549
M=  10.0 C=  7.0 Y=  3.0 RLAM=0.147186D-02 AMTBR=0.0014719 ST= 65.000 AVAIL=0.98395D 00 LQ= 0.2655D-05 L=  0.9549
M=  10.0 C=  6.0 Y=  3.0 RLAM=0.147186D-02 AMTBR=0.0014719 ST= 65.000 AVAIL=0.98394D 00 LQ= 0.4001D-04 L=  0.9549
M=  10.0 C=  5.0 Y=  3.0 RLAM=0.147186D-02 AMTBR=0.0014719 ST= 65.000 AVAIL=0.98387D 00 LQ= 0.4669D-03 L=  0.9553
M=  10.0 C=  4.0 Y=  3.0 RLAM=0.147186D-02 AMTBR=0.0014719 ST= 65.000 AVAIL=0.98305D 00 LQ= 0.4328D-02 L=  0.9590
M=  10.0 C=  3.0 Y=  3.0 RLAM=0.147186D-02 AMTBR=0.0014719 ST= 65.000 AVAIL=0.97552D 00 LQ= 0.3331D-01 L=  0.9868
M=  10.0 C=  2.0 Y=  3.0 RLAM=0.147186D-02 AMTBR=0.0014719 ST= 65.000 AVAIL=0.93769D 00 LQ= 0.2403D 00 L=  1.1875
```

Figure 5.   Intermediate output--sample run 1--first year.

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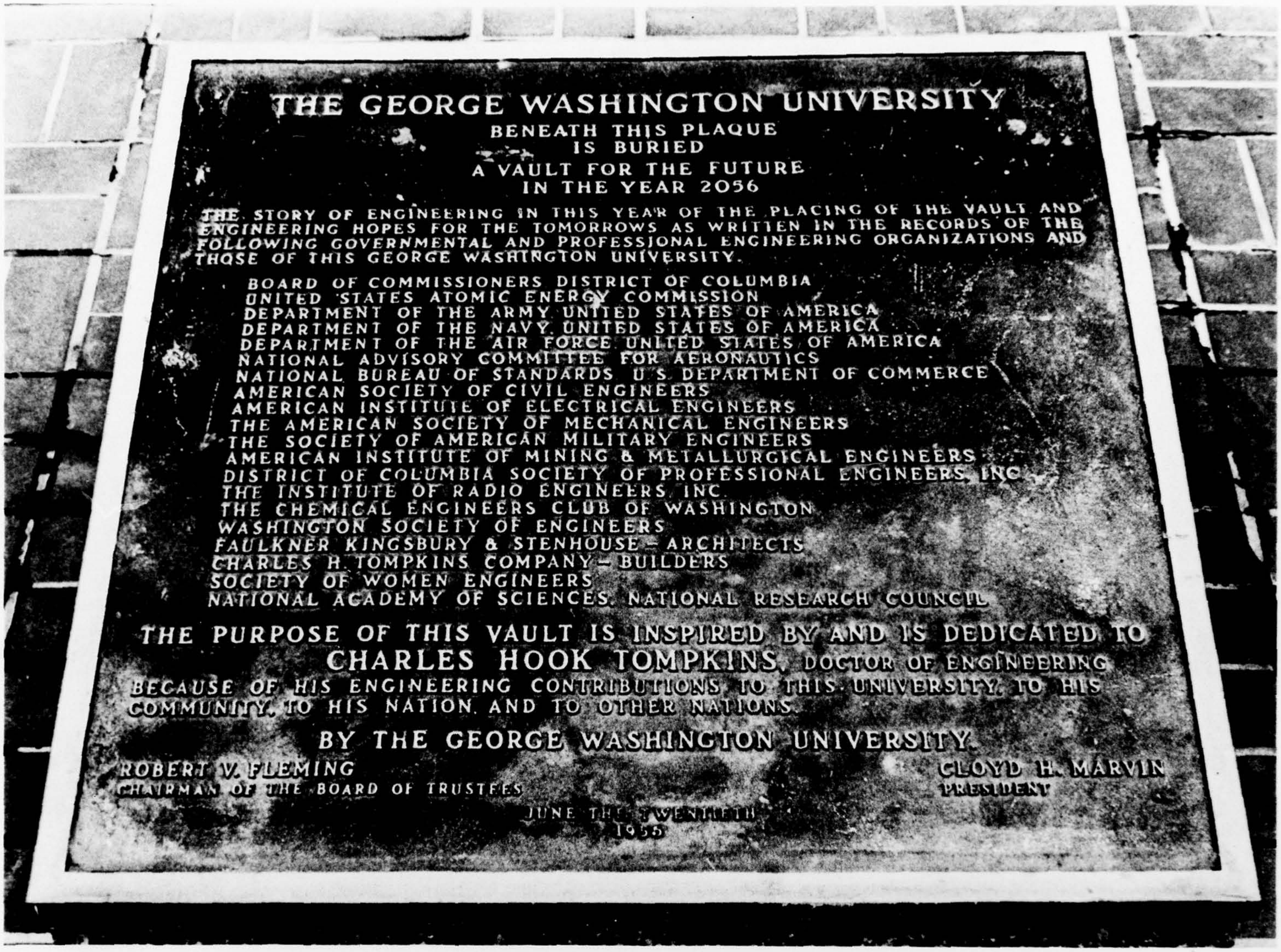

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